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Supersedes NBSIR 77-1305

Provisional Flat Plate Solar Collector Testing Procedures: First Revision

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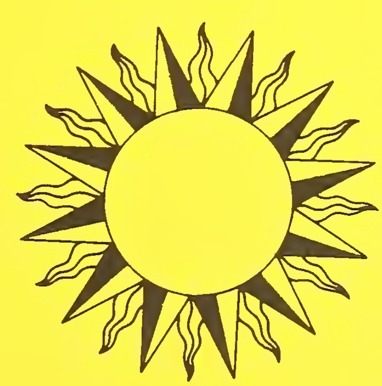
Center For Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

June 1978



Prepared for
Department of Energy
Office of Conservation and Solar Applications
Washington, D.C. 20545

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

PREFACE

This document is the first revision to NBSIR 77-1305, "Provisional Flat Plate Solar Collector Testing Procedures."* The changes made reflect the many comments received as of May 1978.

Many of these testing procedures contained herein are developmental and will be evaluated during a collector testing program being sponsored by the Department of Energy (see Appendix C of this report). Revisions or deletions will be made as more experience is gained and inputs are received from appropriate industry representatives, testing laboratories, designers, etc. Many of the procedures given in this report are intended for use as a supplement to engineering analysis and would ordinarily be performed only when such analysis is not feasible, e.g. with some innovative designs.

Comments concerning these tests are invited and should be addressed to:

Chief, Solar Criteria and Standards Program
National Bureau of Standards
Building 225, Room A-114
Washington, D.C. 20234

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*"Provisional Flat Plate Solar Collector Procedures," September 1977, NBS Report No. NBSIR 77-1305, Available from NTIS, Order No. PB 272 500.

ACKNOWLEDGMENTS

This report is a first revision to NBSIR 77-1305 which was prepared by the Solar Energy Program Team of the National Bureau of Standards, Center for Building Technology, Washington, DC, with the assistance of the Solar Energy Systems Division of Wyle Laboratories, Huntsville, Alabama. Contributors to the NBSIR 77-1305 document included:

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The authors of this report would like to thank the many individuals and organizations, representing the solar industry, standards organizations, professional societies, and testing laboratories for their helpful comments.

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SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

LENGTH

1 in. = 0.0254 meter (exactly)

1 ft = 0.3048 meter (exactly)

AREA

1 $in.^2$ = 6.45×10^{-4} $meter^2$

1 ft^2 = 0.09290 $meter^2$

VOLUME

1 $in.^3$ = 1.639×10^{-5} $meter^3$

1 gal. (U.S. liquid) = 3.785×10^{-3} $meter^3$

MASS

1 ounce-mass (avoirdupois) = 2.835×10^{-2} kilogram

1 pound-mass (avoirdupois) = 0.4536 kilogram

PRESSURE OR STRESS (Force/Area)

1 inch of mercury (60°F) = 3.377×10^3 pascal

1 pound-force/$inch^2$ (psi) = 6.895×10^3 pascal

1 pound-force/$foot^2$ (psf) = 9.930×10^5 pascal

ENERGY

1 foot-pound-force (ft-lbf) = 1.356 joule

1 BTU (International Table) = 1.055×10^3 joule

POWER

1 Watt = 1×10^7 erg/second

1 BTU/hr = 0.2931 Watt

TEMPERATURE

t°C = 5/9 (t°F - 32)

HEAT

1 BTU•in./hr•ft^2•°F = 1.442×10^{-1} W/m•K
(thermal conductivity)

1 BTU/lbm•°F = 4.187×10^3 J/kg•K (specific heat)

1 langley = 4.184×10^4 J/m^2 = 1 cal/cm^2 = 3.69 BTU/ft^2

1.0 INTRODUCTION

1.1 General

This document represents the first revision to NBSIR 77-1305 which contained preliminary testing procedures for evaluation of solar collectors. It is intended for use:

1. As the basis of a testing program to be funded by the Department of Energy (DoE). In this program, which is discussed in Appendix C of this report, approximately 200 different solar collectors will be tested per the thermal performance and 30-day stagnation tests presented in Sections 7.1 through 7.4 of this document. The other tests presented in this document which are considered to be tentative and in need of confirmation or modification will be conducted on approximately 25 different types of collectors selected to be representative of the various types of flat plate collectors currently available.
2. As a resource document in the development of collector testing standards by consensus standards organizations.
3. As a background document by organizations developing programs for the certification of collector performance.

The test methods contained in this report and the provisional rating criteria presented in Appendix A are intended for use in determining the thermal performance, and to assist in the assessment of the safety and durability/reliability of flat plate solar collectors. These test methods and rating criteria have been selected after the review of over 400 accepted industry standards and parallel existent standards where possible. They are consistent with the intent of the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards (MPS) [1]* and the Interim Performance Criteria (IPC) prepared by the National Bureau of Standards (NBS) for DoE and HUD, respectively [2 & 3] and can be used as an aid in determining compliance with these documents.

These test methods and rating criteria are preliminary and will be evaluated during the DoE collector testing program. Revisions or deletions will be made as more experience is gained and inputs are received from appropriate industry representatives, testing laboratories, designers, etc.

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*Numbers in brackets throughout this document indicate references given on Pages 50 & 51.

2.0 GENERAL

2.1 Purpose

The purpose of this document is to set forth interim test methods for determining the performance, reliability, durability and safety of flat plate solar collectors.

2.2 Applicability

The test methods contained herein apply in general only to rigid flat plate solar collectors having the following general characteristics:

2.2.1 Multi- or single-glaze cover

2.2.2 Liquid or air single-phase heat transfer fluid

2.2.3 Single point fluid inlet

2.2.4 Single point fluid exit

2.2.5 Separate thermal storage.

However, individual test methods may be applicable to other collector types.

2.3 Test and Evaluation Methods

Test methods contained herein address the following specific areas:

a. Thermal Performance
b. Reliability/Durability
c. Structural Performance
d. Fire Safety

2.4 Rating Criteria

Preliminary rating criteria are presented in Appendix A for illustrative purposes to show how these tests may be used.

3.0 SELECTION AND CHARACTERIZATION OF TEST SPECIMENS

3.1 Criteria

The test collectors shall be randomly selected from a normal production run and shall be typical of the product to be sold.

3.2 Identification

Each collector submitted for testing shall have permanently affixed thereto the following:

3.2.1 Manufacturer's name and address.

3.2.2 Model name and/or number.

3.2.3 A serial number.

3.3 Materials

Documentation shall be submitted with each collector identifying component materials by commercial designation or composition, including available data to the extent possible concerning the following:

3.3.1 Optical and other properties per Table 2, ASHRAE Standard 93-77 [4].

3.3.2 Insulation and duct liner flame spread per ASTM Standard E-84 [5].

3.4 Specifications

A document shall be furnished with each test specimen providing the following information to the extent possible:

3.4.1 Manufacturer's recommended heat transfer fluid.*

3.4.2 Collector operating parameters.*

3.4.2.1 Recommended operating flow rate.*

3.4.2.2 Recommended fill rate (hot condition).

3.4.2.3 Recommended operating pressure limits.

3.4.2.4 Maximum* and minimum permissable no-flow temperature limitations.

3.4.2.5 Normal operating temperature range.*

3.4.2.6 Additional operating limitations.

---

* Requested in Table 2, ASHRAE 93-77 [4].

3.4.3 Mounting and handling instructions.

3.4.4 Structural load limitations (e.g. design loads).

3.5 Drawings/Manuals

Drawings and/or manuals shall be submitted with each collector in sufficient detail to accurately depict:

3.5.1 Collector dimensions.*

3.5.2 Cover plate dimensions and mounting details.*

3.5.3 Absorber plate details including:

a. Dimensions
b. Fluid capacity
c. Plate and fluid passage material(s)
d. Absorber coating material

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* Requested in Table 2, ASHRAE Standard 93-77 [4].

4.0 RECEIVING INSPECTION

4.1 Damage Inspection

Upon receipt of a collector for testing, the test laboratory will inspect the shipping container for any visible damage.

4.1.1 Should the container show signs of damage, the Receiving Official will document the apparent damage and photograph it as necessary.

4.1.2 Should no apparent damage exist, the Receiving Official will notify the Test Engineer of the specimen's arrival. The Test Engineer will supervise the unpacking. If damage is noted during this process, the Test Engineer will document the damage as in Paragraph 4.1.1 above.

4.2 Documentation Compliance Inspection

In the event the collector has suffered no apparent shipping damage, the Test Engineer will:

4.2.1 Verify receipt of documentation required in Section 3.0.

4.2.2 Inspect the collector to the extent possible without disassembly for compliance to drawings and specifications required in Section 3.0.

4.3 Specimen Rejection

Damaged or incomplete test specimens shall be rejected and the supplier notified.

5.0 RECOMMENDATIONS FOR TEST SEQUENCING

The sequencing recommendations outlined below take into account both technical considerations such as the use of an aging sequence to induce materials degradation prior to testing for rain leakage and the probability that damage will not result from a test and the collector can be used for further testing.

1. The Static Pressure Leakage Test (7.12) should be conducted on the test collectors prior to performing any other tests. This is suggested both to determine the air leakage rate of air collectors which can affect their thermal performance and to detect leaks in liquid collectors which would make them unsuitable for further testing.

2. The thermal performance test sequence should be conducted as follows:

    - o Preconditioning Exposure (7.1.2)
    - o Thermal Performance Baseline Test (7.1.3)
    - o No-Flow 30-Day Degradation (7.2)
        - \+ Thermal Shock/Water Spray Test (7.3)
        - \+ Thermal Shock/Cold Fill Test (7.4)
    - o Post Stagnation Thermal Performance Test (7.1.4)

    The Thermal Shock/Water Spray and Thermal Shock/Cold Fill Tests are to be conducted during the No-Flow 30-Day Degradation test.

3. The Rain Test (7.5) should be conducted on collectors that have been subjected to the No-Flow 30-Day Degradation test in order to assess the effects of materials degradation caused by this test on rain leakage.

4. The Thermal Cycling (7.6), Positive Live Load (7.7), Negative and Combination Wind Loads (7.8), Longitudinal Load (7.9), and Hail Load (7.10) can be conducted in any order desired. However, since the Static Pressure Leakage Test (7.12) is used to indicate damage caused by the first four of these tests, it should be conducted on the test specimens prior to initiating these tests as well as during these tests as specified in the respective test methods.

5. The Air Collector-Rupture and Collapse (7.11) can cause distortion of the collector and should be conducted towards the end of the test sequence.

6. Finally, the Fire Test (7.13) will cause damage to the test collectors and should , therefore, be conducted at the end of of the test sequence utilizing undamaged collectors from the other tests, where possible.

6.0 DOCUMENTATION REQUIREMENTS

6.1 General

Complete records shall be maintained throughout the test program and shall be verified by signatures of the responsible parties for each phase of the program.

All records pertaining to the test program shall be retained by the test laboratory for a minimum period of two years after the conclusion of testing.

6.2 Instrumentation Calibration Records

The test laboratory shall maintain a documented instrumentation calibration system which assures that each instrument used to record test data is calibrated with standards traceable to NBS or in the case of solar insolation to National Oceanographic and Atmospheric Administration (NOAA). A permanent record must be maintained of all calibrations and a recall system employed which prevents an instrument being used after the expiration of its calibration period.

6.3 Test Data

Data sheets shall be maintained and verified by signature of the Test Engineer and the responsible Technicians. All test data shall be recorded, including:

6.3.1 Date and time of test.

6.3.2 Test specimen identification.

6.3.3 Model, serial number and accuracy of each instrument used to measure or record est ata.

6.3.4 Date of the last calibration of each instrument.

6.3.5 All data necessary to verify that the test was performed in accordance with the test procedures.

6.3.6 The result of all visual observations made during and after the test.

6.3.7 A complete description of any failures or anomalies that occur during or as the result of testing.

6.4 Final Report

As a minimum, a report shall be prepared containing the following information concerning each test:

a. Identification of test
b. Test specimen description and identification
c. Summary of results
d. Test conditions
e. Instrumentation and equipment
f. Test results
g. A complete description of any failure, including a photograph of the failure if possible
h. A complete description of any deviation to the test procedure, including unplanned test halts, or of any anomaly occurring before, during or after tests
i. Tables, graphs, charts and photographs as appropriate
j. All-day efficiency data as computed per Appendix B.

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h. A complete description of any deviation to the test procedure, including unplanned test halts, or of any anomaly occurring before, during or after tests
i. Tables, graphs, charts and photographs as appropriate
j. All-day efficiency data as computed per Appendix B.

7.0 TEST METHODS

7.1 Thermal Performance Tests

7.1.1 Purpose

The purpose of the thermal performance tests is to provide collector efficiency data for system design use and to provide a measure of changes in collector performance after environmental exposure. The thermal performance tests are performed in general accordance with the ASHRAE Standard 93-77. A procedure for calculating all-day solar collector efficiency is contained in Appendix B.

7.1.2 Preconditioning Exposure

7.1.2.1 Purpose

The preconditioning exposure is performed to stabilize the collector characteristics prior to thermal performance measurements. This exposure shall be used in lieu of the 1500 $Btu/ft^2 \cdot day$ (17,000 $KJ/m^2 \cdot day$) three-day exposure specified in ASHRAE Standard 93-77.

7.1.2.2 Significance

The collector is exposed to environmental conditions similar to those encountered during the actual thermal test. The exposure conditions are intended to induce the removal of water vapor, final curing of sealants and coatings or other factors that could result in inconsistent thermal performance measurements. This exposure is not intended to influence the collector durability or reliability characteristics.

7.1.2.3 Exposure Procedure

The collector shall be located for a period of at least 24 hours in a building, enclosure or other shaded area where the ambient environment has a temperature in the range of 65 to 100°F (18.3 to 37.8°C) and the relative humidity does not exceed 70 percent. During this period, heat transfer fluid heated to an inlet temperature of between 200 to 220°F (93.3 to 104.4°C) for liquid collectors and 170 to 190°F (76.7 to 87.8°C) for air collectors shall be circulated through the fluid passage ways for a period of at least 8 hours. Fluid flow rates shall be comparable to those used during thermal performance testing. The heat transfer fluid shall be selected from the manufacturer's recommended fluids. The collector shall remain in the same environmental conditions as specified above until ready for mounting on the thermal test apparatus.

7.1.3 Thermal Performance Baseline Test

7.1.3.1 Purpose

The thermal performance baseline measurements provide initial collector efficiency data over a broad range of operating conditions.

7.1.3.2 Significance

The resulting data points will be used to establish a performance curve for comparison with a similar post-measurement made after the 30-day no-flow exposure. The initial performance curve will also be used to establish values of $F_R\ (\tau\alpha)_e$ and $F_R U_L$ for use in calculating allowable variations in peak exposure conditions during the 4-hour period described in the 30-day no-flow test.

7.1.3.3 Test Procedure

The collector shall be mounted and the test conducted using the measurement conditions, sensor accuracies, data analysis and plotting as required by ASHRAE Standard 93-77. A thermal efficiency test at near-normal incidence shall be conducted using at least four inlet temperatures which include one value not greater than 10°F (5.5°C) above ambient, one value not less than 100°F (55.5°C) above ambient with the other two inlet temperatures approximately equally distributed between these two extremes. Four data points shall be taken at each inlet temperature.

The thermal performance baseline test does not require incident angle modifier, response time measurements or the 3-day preconditioning specified in ASHRAE Standard 93-77.

7.1.4 Post Stagnation Thermal Performance Test

7.1.4.1 Purpose

This test is intended to measure the thermal performance of solar collectors following exposure to environmental conditions similar to those which would be expected in actual service.

7.1.4.2 Significance

The thermal performance measurements are performed after the 30-day no-flow exposure described in Section 7.2 which includes thermal shock/water spray tests and a thermal shock/cold fill test. These exposure tests are intended to induce collector material and construction problems similar to those that would occur after

operating the collector for extended periods. The thermal performance measurements made following such environmental exposure are believed to be indicative of the characteristics of solar collectors after long-term exposure.

7.1.4.3 Test Procedure

The requirements, instrumentation, apparatus and method of testing, test procedures and computation, recorded data and test report shall be in accordance with ASHRAE Standard 93-77, except for the preconditioning treatment.

The incident angle modifier and the time constant measurement shall be performed as prescribed in ASHRAE Standard 93-77.

7.2 No-Flow 30-Day Degradation

7.2.1 Purpose

The purpose of this test is to identify in a relatively short time, potential problems with collector materials or construction resulting from prolonged exposure to natural environments.

7.2.2 Significance and Use

Recognizing that elevated temperature is one of the most damaging environments, solar irradiance and ambient temperature levels have been selected which represent typical summer conditions in most U.S. climatic regions. These conditions will produce the temperatures that the various materials used in solar collectors (cover plates, absorptive coatings, sealants, etc.) will experience in use. Until adequate laboratory test procedures are adopted to insure the ability to select reliable materials and designs, an assembly level test is considered to be necessary for evaluating collector reliability.

A 4-hour exposure period with a minimum flux of 300 Btu/ft$^2\cdot$hr (946 W/m^2) is specified in the test method. During this exposure period, it is intended that the collector be exposed to the normal peak profile that it would see on a fixed mount facing South.

The test procedure does not include provisions for evaluating tracking concentrating collectors or collectors used with external reflectors to enhance solar radiation. Modifications to the exposure apparatus may be necessary to accommodate these collectors such as the addition of a reflector for flat plate collectors.

This test method will be superceded as soon as a consensus standard, similar to the test outlined herein, is approved.

7.2.3 Test Specimen

The test specimen shall consist of a complete air or liquid collector panel assembly.

7.2.4 Pre-Exposure Preparation

7.2.4.1 Air Collector duct openings shall be sealed to prevent cooling by convective air flow and the entry of dirt or precipitation. The collector shall be vented to prevent build up of pressure.

7.2.4.2 Liquid Collectors Intended for Use in All Systems (with or without draindown) shall be completely filled with distilled water,* following which the inlet shall be sealed and the outlet provided with a pressure relief valve set to a value between 0% and +10% over the manufacturer's recommended maximum operating pressure.

7.2.4.3 Liquid Collectors Limited to Use in Systems that Draindown when not Operating shall be completely filled with distilled water,* following which the fluid shall be allowed to gravity drain for 15 minutes with the collector mounted at a 45° tilt angle. The collector inlet shall then be protected to prevent entry of dirt or precipitation. The collector shall also be vented to prevent build up of pressure.

7.2.5 Exposure Conditions

7.2.5.1 Exposure conditions shall consist of 30 days of cumulative exposure to a minimum daily incident solar radiation flux of 1500 $Btu/ft^2 \cdot day$ (17,000 $KJ/m^2 \cdot day$) as measured in the plane of the collector aperture. The exposure conditions shall include at least one consecutive 4-hour period with a minimum instantaneous flux of 300 $Btu/ft^2 \cdot hr$** (946 W/m^2). This exposure must occur after the collectors have boiled dry, where applicable.

7.2.5.2 The average baseline ambient temperature shall be 80°F (26.7°C) or higher during the 4-hour exposure period.

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* Manufacturer's/designer's recommended fluid shall be used in those instances when they specifically prohibit the use of distilled water.

** Collector orientation changes to maximize the solar radiation or supplementary reflectors may be necessary to obtain the 300 $Btu/ft^2 \cdot hr$ (946 W/m^2) insolation level at certain locations. However, the maximum peak flux shall not exceed 370 Btu/ft^2 (1165 W/m^2) under normal sun-sky or simulator exposure conditions.

If the ambient temperature values recorded during the 4-hour exposure period do not reach the minimum, trade-offs between insolation and ambient temperature can be made to meet these requirements. When these trade-offs are made, the plate temperature (t_p) shall equal or exceed the plate temperatures that would occur in the collector when exposed to a daily radiation cycle on a fixed rack during the 4-hour 300 Btu/ft^2·hr (946 W/m^2) or greater condition with an ambient temperature of 80°F (26.7°C). The ambient temperature shall not be less than 70°F (21.1°C) when such trade-offs are made.

The relationship between solar irradiance, ambient temperature and plate temperature shall be calculated using the following procedure:

The collector efficiency is expressed by

$$\eta = F_R(\tau\alpha)_e - \frac{F_RU_L(t_i-t_a)}{I} \qquad (1)$$

At the condition where the efficiency, η, equals zero, $t_i=t_p$ and

$$F_R(\tau\alpha)_e = F_RU_L \frac{t_p-t_a}{I} \qquad (2)$$

or

$$t_p = I \frac{F_R(\tau\alpha)_e}{F_R U_L} + t_a \qquad (3)$$

Values of $F_R(\tau\alpha)_e$ and F_RU_L can be obtained from the intercept and slope of the thermal performance curves established by the initial efficiency measurements described in Section 7.1.3. The value of F_RU_L is a constant for collectors conforming to a straight line (linear) relationship between efficiency, η, and $\Delta t/I$.

If a second order curve is required to fit the thermal performance data points, then the value of F_RU_L should be obtained in the region of the last data points using the first derivative of the equation for the curve. Therefore, using $\eta = F_RU_L[A \pm B\Delta t/I \pm C(\Delta t/I)^2]$ the first derivative with respect to $\Delta t/I$ is $F_RU_L = \pm B - 2C\Delta t/I$

The revised exposure conditions required to achieve an equivalent t_p can then be calculated using Equation (3) as follows:

$$I_1 \frac{F_R(\tau\alpha)_e}{F_RU_L} + t_{a,1} = I_2 \frac{F_R(\tau\alpha)_e}{F_RU_L} + t_{a,2} \qquad (4)$$

substituting the minimum values in Equation (4) gives:

$$I_2 = \left[300 \frac{F_R(\tau\alpha)_e}{F_R U_L} + 80 - t_{a,2}\right]\left[\frac{F_R U_L}{F_R(\tau\alpha)_e}\right] \tag{5}$$

and finally the irradiance required to compensate for ambient temperature below 80°F (27°C) can be calculated by:

$$I_2 = 300 + \left[80 - t_{a,2}\right]\left[\frac{F_R U_L}{F_R(\tau\alpha)_e}\right] \tag{6}$$

7.2.6 Data Requirements

7.2.6.1 The exposure conditions including hourly insolation, ambient temperature, wind velocity and daily precipitation shall be recorded to enable determination of the average daily values. Insolation and ambient temperature values shall be recorded every 30 minutes during the 4-hour 300 Btu/ft^2·hr (946 W/m^2) minimum flux exposure period.

7.2.6.2 A regularly scheduled weekly visual inspection shall be made and a record of changes in the physical construction or appearance of the collector maintained.

7.2.6.3 The results of the pre-test and post-test thermal performance shall be plotted on the same graph for comparison purposes. A written description of observed changes in the physical or optical appearance of the collector shall be reported and substantiated with photographs where appropriate.

7.3 <u>Thermal Shock/Water Spray Test</u>

7.3.1 <u>Purpose</u>

The purpose of this test is to determine the ability of a solar collector to withstand thermal shock caused by heavy rain falling on the heated collector.

7.3.2 <u>Test Specimen</u>

The test specimen shall consist of a complete air or liquid solar collector panel assembly undergoing 30-day no-flow testing. The inlet, outlet and vent ports not normally exposed to rain shall be sealed. To assure that the collector has reached stagnation temperature, the spray test shall be conducted after at least one hour of exposure to direct sun with a minimum irradiance of 270 $Btu/ft^2 \cdot hr$ (850 W/m^2) measured in the plane of the collector. The test shall be conducted between the 20th and 30th exposure days.

7.3.3 <u>Apparatus</u>

The apparatus consists of a distilled* water-spray system designed to provide the specified quantity of water in such a manner as to wet the collector uniformly and to wet those areas vulnerable to water penetration during normal exposure to rain. The temperature of the water shall be within $75 \pm 10°F$ ($23.9 \pm 5.5°C$) during the test.

7.3.4 <u>Procedure</u>

<u>STEP 1</u> - Adjust the water spray to provide not less than 1.8 gal/ft^2 of collector area per hour.

<u>STEP 2</u> - Direct spray onto collector in such a manner as to wet the surface that would be wet during a normal rain shower. Maintain water spray for five (5) minutes.

<u>STEP 3</u> - Turn off the water spray and dry exterior surfaces of the collector.

<u>STEP 4</u> - Inspect collector for evidence of water penetration into the interior.

<u>STEP 5</u> - Repeat Steps 1, 2, 3 and 4 on three different days.

7.3.5 <u>Data Requirements</u>

Document visual evidence of physical damage and water or moisture penetration within the collector hcusing.

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*Tap water may be used where mineral deposit buildup does not cause visual obscuration of the cover plate.

7.4 Thermal Shock/Cold Fill

7.4.1 Purpose

The purpose of this test is to evaluate the reliability of a solar collector after being subjected to thermal shock and boiling stresses induced by filling the hot collector with relatively cool heat transfer fluid during daytime start-up.

7.4.2 Test Specimen

The test specimen shall consist of a complete air or liquid collector panel assembly undergoing 30-day no-flow testing. To assure that the collector has reached stagnation temperature, the test shall be conducted after at least one hour of exposure to direct sun with a minimum irradiance of 300 Btu/ft^2·hr (946 W/m^2) measured in the plane of the collector.*

7.4.3 Apparatus

The apparatus consists of a water or air source capable of providing the required quantity of fluid at the manufacturer's specified fill or flow rate. The temperature of the fluid induced into the collector shall be within 75°F$\pm$10°F (23.9$\pm$5.5°C).

7.4.4 Procedure

STEP 1 - Assure that the collector has reached stagnation temperature.

STEP 2 - Induce fluid flow at the manufacturer's recommended fill or flow rate.**

STEP 3 - Maintain flow for 5 minutes.

STEP 4 - Turn off fluid flow and perform static pressure leakage test in accordance with Paragraph 7.12, "Static Pressure Leakage Test."

STEP 5 - Blow out residual water (liquid collectors).

STEP 6 - Reseal inlet and outlet ports.

7.4.5 Data Requirements

Document any physical damage or leakage resulting from this test.

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* Collectors that have not completely boiled out will be drained prior to conducting this test.

**When the flow rate is not specified, a rate of 1.5 gph/ft^2 for liquid-filled collectors and 2 SCFM/ft^2 for air-filled collectors shall be used.

7.5 Rain Test

7.5.1 Purpose

The purpose of this test is to determine the resistance of the solar collector to water penetration when subjected to wind-driven rain.

7.5.2 Significance and Use

The rain spray test described below as Method 1 is based upon ASTM Standard E331 [6] which is intended for use in the evaluation of exterior windows, curtain walls and doors. This method includes the use of a pressure differential to enhance the penetration of water into the assembly being tested. This type of pressure differential can occur with many types of solar collector mounting configurations. In the case of solar collectors that form a building element, e.g. a roof, this pressure differential will be caused by differences of pressure inside and outside the building. In the case of solar collectors mounted on standoffs or racks, this pressure differential will be caused by positive and negative wind forces acting simultaneously on opposite faces of the collector.

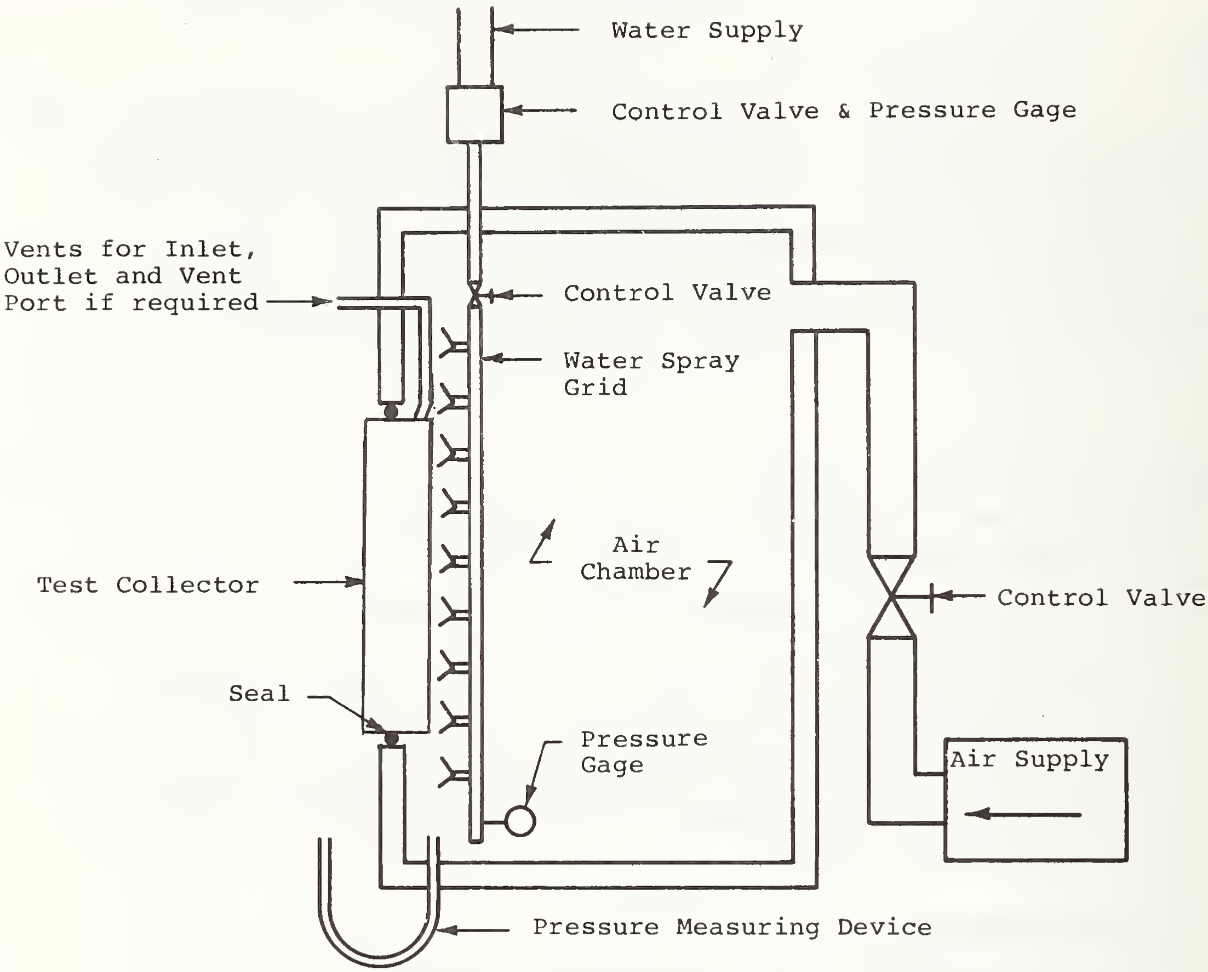
A second testing procedure, Method 2, included in this section is based upon a rain penetration test, utilized by Underwriters Laboratories [7]. This method does not include the use of a pressure differential and is included in this document for use in the DoE collector testing program to determine whether or not it produces results comparable to those that would be obtained with the ASTM E331 method.

7.5.3 Test Specimen

The test specimen shall consist of a complete air or liquid collector panel assembly.

7.5.4 Apparatus

Method 1: The collector shall be mounted in the apparatus illustrated in Figure 1 or any arrangement of equipment capable of performing the test procedure in a similar manner. The water-spray system shall have nozzles spaced to wet those areas vulnerable to water leakage. For additional details on construction and calibration of the water-spray system, consult ASTM Standard E331 [6]. The test consists of sealing the solar collector into or against one face of a test chamber, and supplying air to or exhausting air from the chamber at a rate required to maintain



NOTE: For a negative pressure system, the water-spray grid would be located outside the chamber and the air supply would be replaced by an air-exhaust system.

FIGURE 1. APPARATUS FOR RAIN TEST

the test pressure difference across the collector, while spraying water onto the face of the collector at the required rate.

Method 2: The collector shall be mounted on a rack at an angle of 45° to the horizontal. The rain test apparatus is to consist of three spray heads mounted in a water supply rack as shown in Figure 2.a. Spray heads are to be constructed in accordance with Figure 2.b. The water pressure for all tests is to be maintained at 5 psi (34.47 kPa) at each spray head. The distance between the center nozzle and the unit is to be approximately 3 feet (0.91 m). The unit is to be brought into the focal area of the three spray heads in such position and under such conditions that the greatest quantity of water will enter the unit. The spray is to be directed downward at an angle of 45° to the cover plate of the collector and separately at an angle of 22 1/2° to the back surface of the collector.

7.5.5 Procedure

STEP 1 - Weigh the collector.

STEP 2 - Mount the collector in the test apparatus with the glazing exposed to the water spray and remove any sealing material or construction that is not normally a part of the assembly as installed in or on a building. Inlet, outlet and vent ports not normally exposed to rain shall be vented to outside the test chamber.

STEP 3 -

Method 1 Only

o Adjust the water spray to provide a uniformly distributed spray at the rate of 5.0 gph/ft^2 over the entire collector top surface.

o Apply an air-pressure difference of 10 lbf/ft^2 (1.92 inches head of water).

o Maintain air-pressure difference and water spray for 15 minutes.

o Remove the air-pressure difference and stop the water spray.

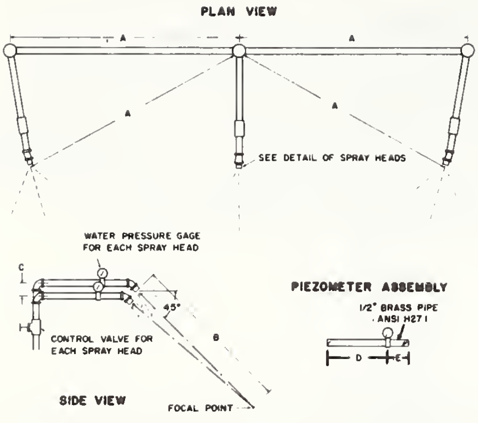
Method 2 Only

o Position the spray apparatus to direct a downward spray from a distance of 3 feet at an angle of 45° with the collector cover plate surface.

o Adjust the water pressure at each spray head to 5 psi.

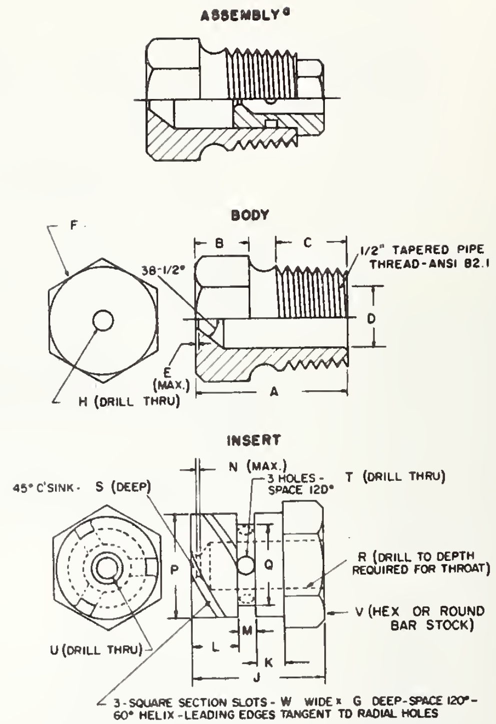
o Maintain the water spray for 1 hour.

STEP 4 - Dry exterior collector surfaces and weigh the collector. Observe and record the points of water penetration into the collector interior.



Item	inch	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

FIGURE 2A



Item	inch	mm	Item	inch	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.79
H	(No.9)[b]	5.0	U	(No. 40)[b]	2.49
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

a - Molded nylon Rain-Test Spray Heads are available from Underwriters' Laboratories, Inc.

b - ANSI B94.11 Drill Size.

c - Optional - To serve as wrench grip.

FIGURE 2B

FIGURES 2A and 2B. RAIN TEST APPARATUS FOR METHOD 2

STEP 5 -

Method 1 Only*

o Mount the collector in the test apparatus to expose the opposite side; or the water-spray system may be moved outside the test chamber and a negative pressure applied in the test chamber.

o Repeat Step 3 with a water spray and air-pressure difference of 1/2 the values (2.5 gph/ft^2 and 5 lbf/ft^2).

Method 2 Only*

Expose the collector back surface to a water spray directed downward at an angle of 22 1/2° with respect to the collector back surface.

STEP 6 - Repeat Step 4.

7.5.6 Data Requirements

Document any change in weight or visual evidence of water or moisture penetration resulting from the rain test.

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*Applies only to collectors that are exposed to wind-driven rain on back surface or edges.

7.6 Thermal Cycling

7.6.1 Purpose

The purpose of this test is to insure that solar collectors that are intended for use in freezing conditions will perform reliably after exposure to such conditions.

7.6.2 Significance and Use

The test is intended to induce the stresses due to differential thermal expansion and heat transfer fluid freezing, if any, that would occur in solar collectors when they are used in accordance with their manufacturer's recommendations. Collectors that can be subjected to freezing conditions according to their manufacturer will be so tested. Similarly, collectors that are recommended for use with water when provision is made for draindown under freezing conditions will be tested under these conditions and when fluids other than water are recommended for use under freezing conditions, these fluids will be used. Two alternate testing procedures are presented. The first consists of cycling the collector in a controlled temperature chamber. The second procedure, which is included in this document as an alternative for use in the DoE collector program for comparative testing purposes, consists of thermal cycling the collector by allowing it to be cooled in a refrigerated chamber and then removing it from the chamber and allowing it to warm up under ambient conditions. Neither of the two test procedures are based on existent standards and should be considered developmental in nature at the present time.

7.6.3 Test Specimen

The test specimen shall consist of a complete air or liquid collector panel assembly. The initial leakage rate of the specimen shall be determined in accordance with Paragraph 7.12. In addition:

A. Air Collector inlets shall be equipped with a check valve and desiccant to allow the admission of dry air, if internal pressures of less than one atmosphere occur.

B. Liquid Collectors Intended for Use in all Systems (with or without draindown) shall be completely filled with the manufacturer's recommended fluid, following which the inlet shall be sealed and the outlet provided with a pressure relief valve set to a value between 0% and +10% over the manufacturer's recommended maximum operating pressure.

C. Liquid Collectors Limited to Use in Systems that Draindown When not Operating shall be completely filled with the collector manufacturer's recommended fluid (usually water), following which the fluid shall be allowed to gravity drain for 15 minutes with the collector mounted at a 45° tilt angle.

D. A Temperature Sensing Device shall be installed in the collector inlet or outlet as close to the absorber plate as possible, and connected to a direct reading device outside the test chamber.

7.6.4 Apparatus

Method 1: A temperature chamber capable of cycling the enclosed temperature region from 70±10°F (21±5.5°C) to -25°F (-32°C) at a rate of 40F° to 60F° (22C° to 33C°) per hour.

Method 2: A temperature chamber, held at -25°F (-32°C), capable of cooling a solar collector placed in it at 70±10°F (21±5.5°C) down to -10°F (-23°C) at a rate of 40F° to 60F° (22C° to 33C°) per hour.

7.6.5 Procedure

STEP 1 - Place the collector in the temperature chamber mounted at the 45° tilt angle in a manner that simulates in-use constraints.

STEP 2 -

Method 1 Only

o Lower the internal chamber temperature to -25°F (-32°C) at a rate of 40F° to 60F° (22C° to 33C°) per hour and maintain until the temperature sensor reaches -10°F (-23°C). Lower test temperatures should be used when specified by the collector manufacturer.

o Raise the internal chamber temperature to (70±10°F[21±5.5°C]) at a rate of 40F° to 60F° (22C° to 33 C°) per hour and maintain until the temperature sensor reaches ambient temperature.

Method 2 Only

o Place the collector in a chamber cooled to -25°F (-32°C) and maintain until the temperature sensor reaches -10°F (-23°C). Lower test temperatures should be used when specified by the collector manufacturer.

o Remove the collector from the chamber and allow it to warm up under ambient conditions maintained at 70±10°F (21±5.5°C).

STEP 3 - Repeat Step 2 for a total of ten (10) cycles.

STEP 4 - Perform static pressure leak test in accordance with Paragraph 7.12 to determine structural integrity.

7.6.6 Data Requirements

Document any visual evidence of damage, evidence of moisture buildup, and leakage per Paragraph 7.12.

7.7 Positive Live Loads

7.7.1 Purpose

The purpose of this test is to determine the ability of a flat plate collector to function satisfactorily after being subjected to uniformly distributed loads resulting from snow or positive wind pressure, whichever predominates.

7.7.2 Significance and Use

This test is intended to determine the capability of a rigid flat plate collector design to safely withstand the positive loads imposed by snow or wind pressure on the cover plate surface of the collector and its ability to function satisfactorily following application of such loads. This test method does not include application of the negative wind loads on the back surface of an exposed collector.

The maximum load (Rm) to be imposed by this procedure shall be based on the manufacturer's design load rating (U) for positive pressure on cover plate increased by a suitable safety factor (Appendix A7). <u>In the absence of a manufacturer's design load rating</u>, the maximum load to be imposed shall be 135 psf. The maximum load of 135 psf was obtained by using a safety factor of approximately three in conjunction with the pressure caused by a wind speed of 100 mph on a vertical flat plate collector mounted at a height of 250 ft on a building with exposure "C" (in accordance with ANSI A-58.1 [8]).* The selection of 100 mph wind represents the maximum expected wind speed in the United States for a 25-year mean recurrence interval. This test is intended to be a design qualification test and not routinely to be performed on all collectors of a particular design. The method is based on an established procedure (ASTM E72) [9], but the applicability of this procedure to flat plate solar collectors remains to be evaluated by means of the DoE solar collector testing program.

The method is intended for use with rigid flat plate collectors. Its application to other types of collectors has not been determined.

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*Considered as "parts or portions" on windward wall of a building.

7.7.3 Test Specimen

The test specimen shall consist of a complete air or liquid collector unit including mounting brackets or fixtures normally supplied with or specified by the manufacturer of the collector, and the fixtures and fittings required to perform the "Static Pressure Leakage Test" specified in Section 7.12.

7.7.4 Apparatus

The collector to be tested shall be mounted in the apparatus illustrated in Figure 3. The collector shall be supported on the test bed in accordance with the manufacturer's recommendations. Connect with tie rods to the test bed a reaction platform wider and longer than the area to be loaded and parallel to the face to be loaded. The area of the collector to be loaded shall be that surface which is exposed to wind forces, exclusive of collector mounting brackets, if any. Place an airtight bag (20-mil PVC plastic film or other pliable material) as wide and as long as the area to be loaded, between the specimen and the reaction platform. Apply a load to the specimen by increasing the air pressure in the bag. Measure the pressure with an accuracy of 2% by means of a manometer or other pressure measuring device.

7.7.5 Procedure

STEP 1 - Mount the collector in the loading apparatus such that the glazing surface is subjected to the applied load.

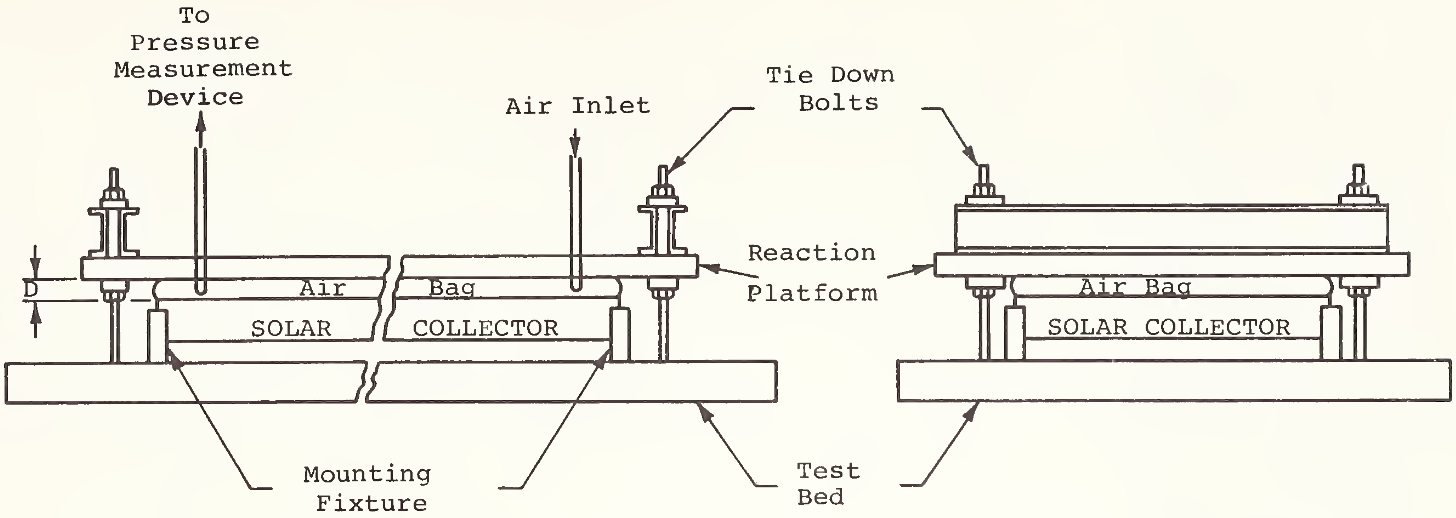
STEP 2 - Determine the initial leakage rate of the collector in accordance with Section 7.12.

STEP 3 - Apply a uniform load of 1/3 Rm at the rate of 5 psf per minute. During application of the load, make observations of any physical damage, noticeable deformation or distortions and note the load at which they occur. Discontinue testing when a failure occurs.

STEP 4 - Maintain the load for a period of ten minutes and then release the applied load.

STEP 5 - Determine the leakage rate in accordance with Section 7.12.

STEP 6 - Repeat Steps 3, 4 and 5 and increase the applied load in increments of 1/3 Rm until some type of physical damage is observed or a maximum of Rm is reached.



D = Distance between specimen and reaction platform

D ≅ 1 inch plus thickness of collapsed air bag at its thickest point. Reaction platform should be rigid enough that the deflection under expected load is small, i.e., less than 1/4 inch.

FIGURE 3. APPARATUS FOR POSITIVE LIVE LOAD TEST

7.7.6 Data Requirements

The following data shall be recorded:

A. Complete description of the collector and method of mounting to the test bed.
B. Leakage rates, initial and at end of each load cycle.
C. The maximum load applied.
D. The physical damage, distortion or other structural problems observed during or following the test.
E. Applied load at which physical damage, distortion or other structural problems occurred.

7.8 Negative and Combination Wind Loads

7.8.1 Purpose

The purpose of this test is to determine the ability of a flat plate collector to function satisfactorily after being subjected to uniformly distributed loads resulting from either of the two following cases. Case 1 applies when the wind has access only to the cover plate surface of the collector and creates a suction (negative load) on that surface. Case 2 applies when the wind has access to both surfaces of the collector and would create a combination of suction on the cover plate surface and uplift (positive pressure) on the back surface.*

7.8.2 Significance and Use

This test is intended to determine the ability of a rigid, flat plate collector design to safely withstand the uniform loads created by either a negative wind pressure on the cover plate surface or a combination of that negative pressure with a positive wind pressure on the back surface.

The maximum load (Rm) to be imposed by this procedure shall be the manufacturer's design load ratings (U) for the two loading conditions increased by a suitable safety factor (Appendix A7/A8). In the absence of the manufacturer's design load ratings, the maximum load to be imposed on each surface shall be 120 psf. The maximum load of 120 psf was obtained by multiplying with a safety factor of approximately three, the pressure caused by a wind speed of 100 mph on a collector mounted at 45° and away from the roof edge on a 250 ft high building with exposure "C" (in accordance with ANSI A-58.1 [8]).** The 100 mph wind speed represents the maximum expected in the United States for a 25-year mean recurrence interval.

Although the method of applying the positive load to the back face of the collector is based on an established procedure (ASTM E72 [9]) these test procedures should be considered developmental at the present time and may not be applicable when testing collectors with corrugated, curved, or thin film glazing.

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* Case 2 is applicable where the collector is mounted on an open rack or any portion of its back surface is eight (8) inches from the mounting surface.

**Considered as "solid signs" on a roof within 1/4 h of the roof surface where h is the height of the collector.

7.8.3 Test Specimen

The test specimen shall consist of a complete air or liquid collector unit including mounting brackets or fixtures normally supplied or specified by the manufacturer of the collector, and the fixtures and fittings required to perform the "Static Pressure Leakage Test" specified in Section 7.12.

7.8.4 Apparatus

The test specimen shall be mounted to the test bed in accordance with the manufacturer's instructions and as illustrated in either Figure 4 or Figure 5. Collectors with rigid flat glazing materials shall be tested using Method 1 with the apparatus shown in Figure 4. Collectors which cannot be suction loaded with the equipment for Method 1 (i.e. corrugated, curved or thin film glazings) shall be tested using Method 2 with the apparatus shown in Figure 5. The load measuring equipment, load cell, manometer, etc. shall be capable of measuring the applied loads with an accuracy of 2%. An air bag as described in Section 7.7 is placed under the specimen to provide uplift for Case 2 tests.

Method 1: The apparatus for Method 1, Figure 4, consists of a series of vacuum lift cups (glass handling equipment) applied to the glazing and attached to an articulated whiffle tree arrangement.

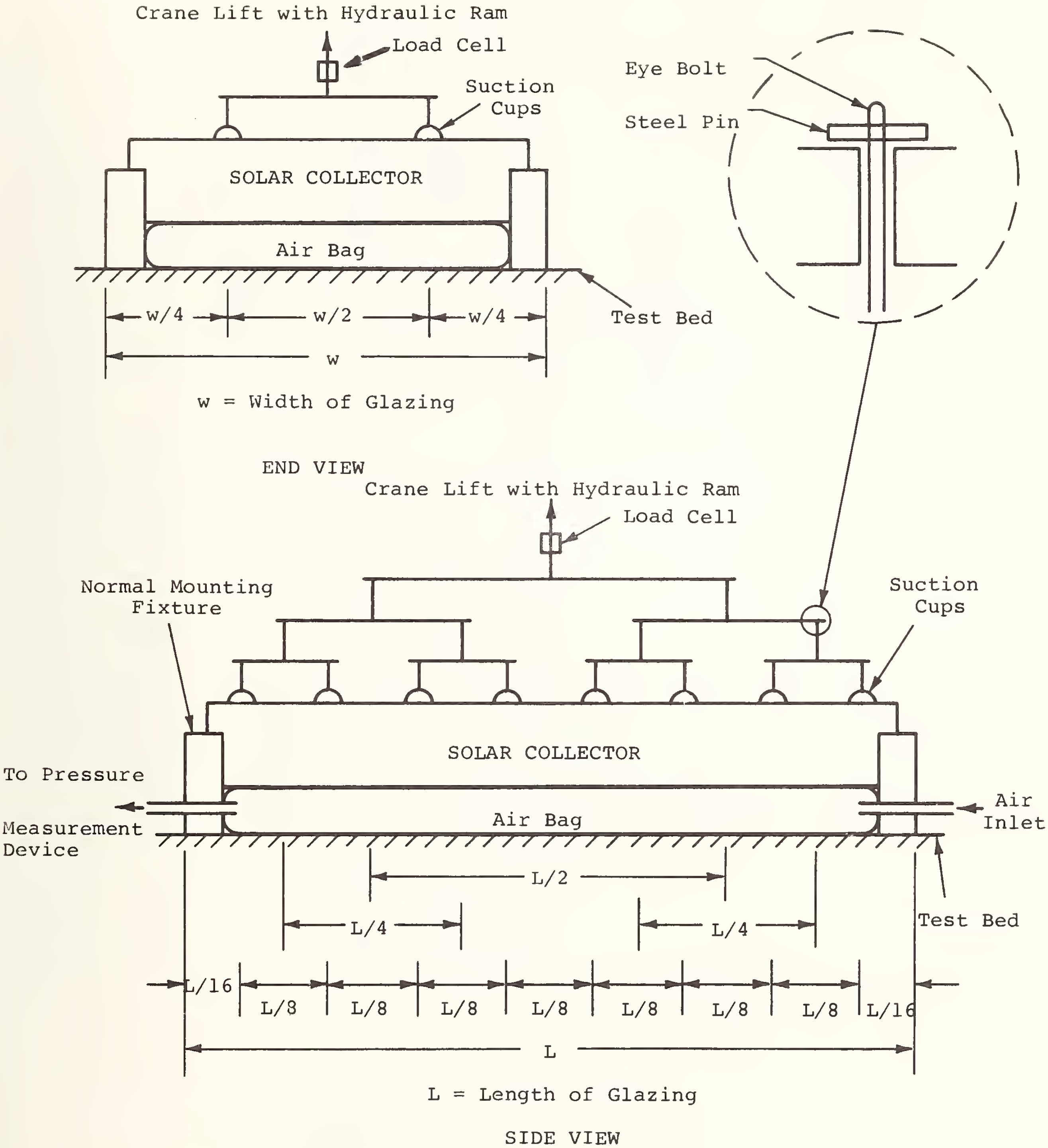
Method 2: For Method 2, Figure 5, the apparatus consists of a vacuum chamber with the collector forming one side of the chamber and includes a vacuum device capable of providing the required load.

7.8.5 Procedure

The loads applied under these procedures are the sum of the suction and the uplift loads for the Case 2 test and suction load only for the Case 1 test. The suction and uplift loads are equal for the Case 2 test.

STEP 1 - Mount the specimen to the test bed so that the glazing surface will be lifted by the applied suction loads. For Case 2 tests, clearance must be provided for installation of the air bag between the test bed and the specimen.

STEP 2 - Determine the initial leakage rate of the collector in accordance with Section 7.12.



NOTE: The number of suction cups shall be 2^n (where n is an integer).

FIGURE 4. METHOD 1 - APPARATUS FOR NEGATIVE LIVE LOAD TEST (Air bag for Case 2 only)

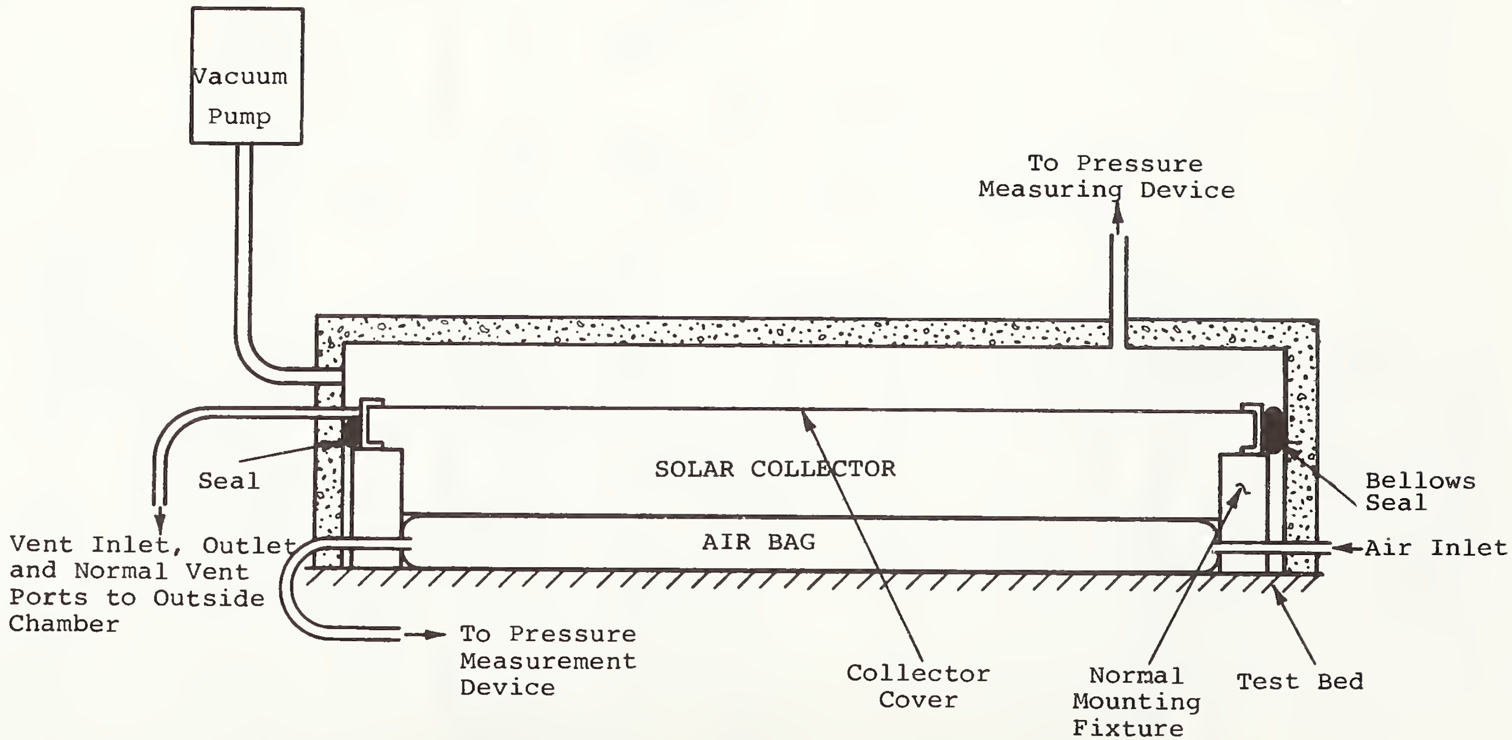


FIGURE 5. METHOD 2 - APPARATUS FOR NEGATIVE LIVE LOAD TEST
(Air bags for Case 2 only)

STEP 3 - Apply a load of 1/3 Rm to each surface to be tested at a rate of 10 psf per minute. For Case 2 tests this load is applied simultaneously in both suction and uplift for a total of 2/3 Rm. During application of the load make observations relative to any physical damage, noticeable deformation, or distortion and note the load at which they occur. Discontinue testing if a failure occurs.

STEP 4 - Maintain the load for one (1) minute and then gradually remove the load.

STEP 5 - Determine the leakage rate of the collector in accordance with Section 7.12.

STEP 6 - Repeat Steps 3, 4 and 5, but increase the applied load in increments of 1/3 Rm until some type of physical damage is observed or to a maximum of Rm. For Case 2 tests the increments shall be 1/3 Rm on each surface and the maximum shall be Rm on each surface.

7.8.6 Data Requirements

The following data shall be reported:

A. Complete description of collector and method of mounting onto the test bed.
B. The test apparatus used (Method 1 or 2).
C. The type of test performed (Case 1 or 2).
D. The leakage rate (initial and at the end of each 1/3 Rm load cycle).
E. A description of any physical damage or distortions observed during and after the tests.
F. The applied load at which physical damage, distortion or other structural problems occurred.

7.9 Longitudinal Loads

7.9.1 Purpose

The purpose of this test is to determine the ability of the collector mountings* to withstand cyclic loads in the plane of the longitudinal axis of the collector.

7.9.2 Significance and Use

This test is intended to determine the ability of the mounting for a rigid, flat plate collector to withstand the cyclic loads such as are induced by the vibration of the collector from wind gusts or of the structure on which the collector is mounted.

The load to be imposed by this procedure is intended to simulate the inertial loads of a filled collector on its mountings when installed vertically or at an angle.

This test is primarily intended to be performed on innovative mounting designs which are not conducive to engineering analysis. It is not intended as a routine test to be performed on all collector mountings or on all mounting designs.

This test is developmental in nature and is not intended for use in other than exploratory testing at this time.

7.9.3 Test Specimen

The test specimen shall consist of a complete collector panel and any mounting brackets or fixtures normally supplied with it or specified by the manufacturer. The specimen shall be mounted in the test apparatus in accordance with the manufacturer's normal mounting instructions. All collectors shall be sealed and capped. Liquid collectors shall be completely filled with tap water.

Note: Bleeder valves or petcocks should be provided at the highest point in the system to permit venting of all air during the filling operation.

*The hardware used to attach or connect the collector to its support structure.

7.9.4 Apparatus

This test may be performed using either one of the two methods discussed below. When tested by Method 1, the collector is tested horizontally with the apparatus illustrated in Figure 6. When tested by Method 2, the collector is tested vertically with the apparatus illustrated in Figure 7. The loads are to be applied through a distribution pad to the geometric center of the collector side which has been designated by the manufacturer to be uppermost when installed. The distribution pad shall be designed to provide an essentially uniform load over a minimum area of 50% of the loaded side. The line of action for the load shall be parallel to the absorber plate and perpendicular to the loaded side. The loading equipment shall be capable of applying loads with an accuracy of 1%.

Method 1: The test apparatus shall consist of a hydraulic jack or other equivalent means for maintaining a pre-load and imposing an additional load on the collector. The pre-load force shall be equal to the maximum filled weight of the collector. The imposed additional load shall be equal to 50% of the maximum filled weight of the collector. The pre-load shall be maintained on the specimen for the duration of the test.

Method 2: The test apparatus shall consist of weights or other equivalent loading methods that will apply a load parallel to the long axis of the test specimen. Provisions shall be made to remove the load as quickly as possible.

7.9.5 Procedure

7.9.5.1 Method 1 (Horizontal Test)

STEP 1 - Mount the collector parallel to the test bed as illustrated by Figure 6.

STEP 2 - Attach the loading device so that the load will be imposed parallel to the test bed and through the geometric center of the collector. Apply the pre-load force.

STEP 3 - Increase the load to 150% of the maximum filled collector weight at a rate faster than 25% of filled weight per second and hold for two (2) minutes.

STEP 4 - Reduce the load to the pre-load value as quickly as possible.

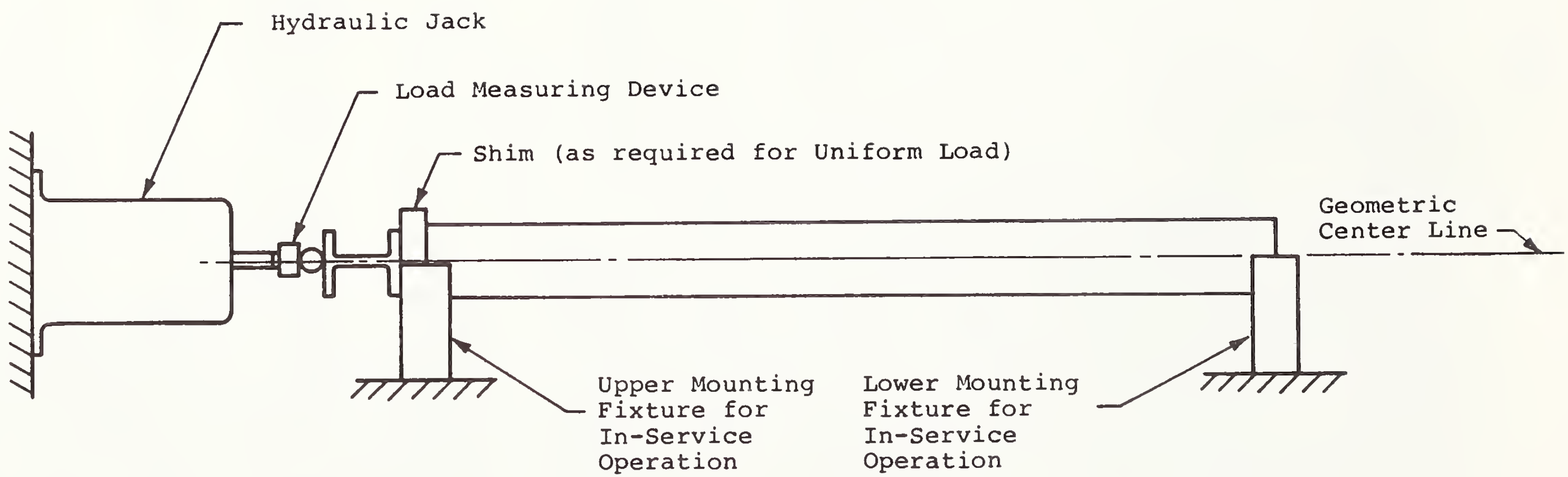


FIGURE 6. METHOD 1 - APPARATUS FOR HORIZONTAL LOAD TEST

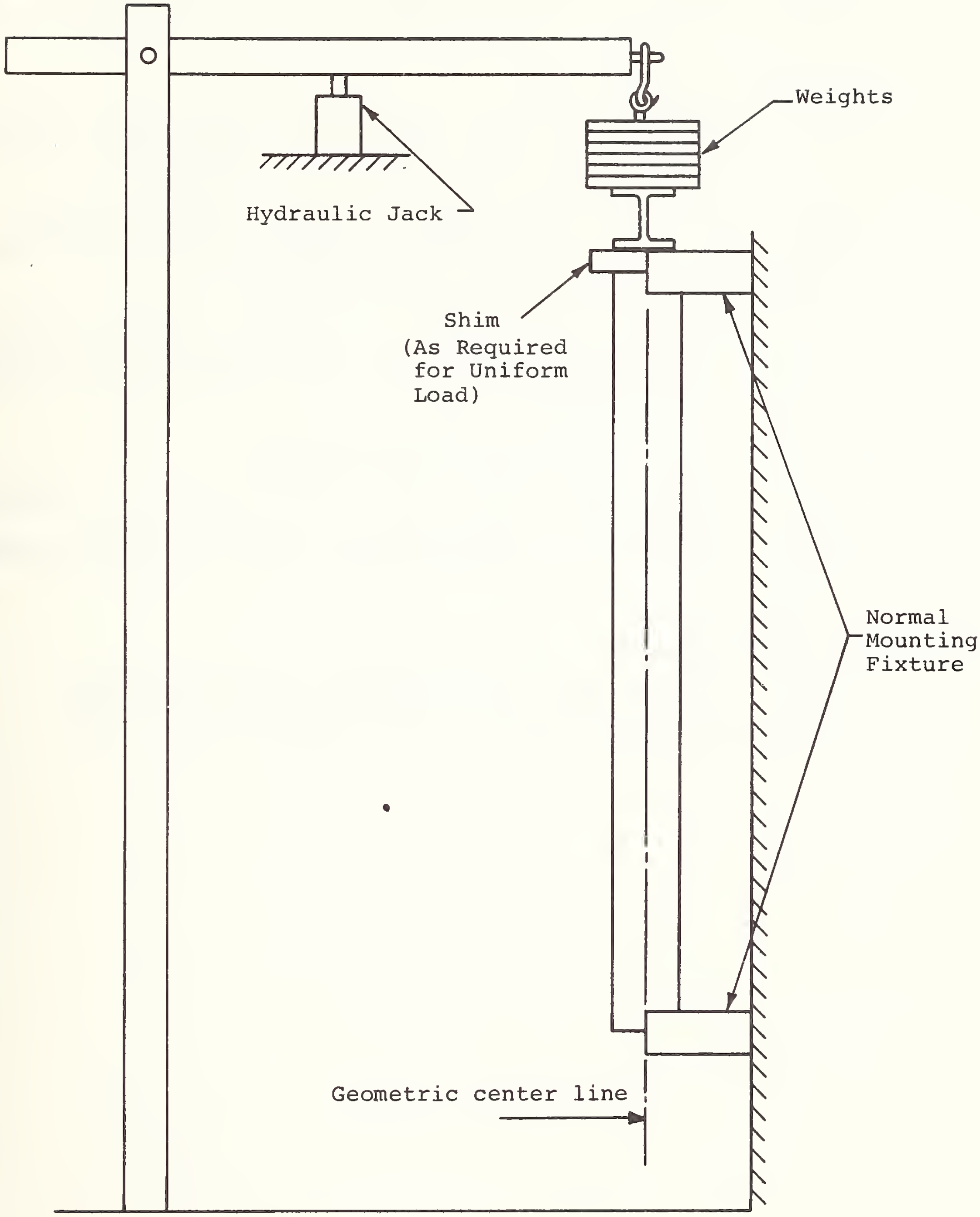


FIGURE 7. METHOD 2 - APPARATUS FOR VERTICAL LOAD TEST

STEP 5 - Repeat Steps 3 and 4 for a total of fifty (50) cycles.

STEP 6 - Inspect the collector and mountings for physical damage or distortion.

7.9.5.2 Method 2 (Vertical Test)

STEP 1 - Mount the collector parallel to a flat, rigid, vertical test frame such as the wall illustrated in Figure 7.

STEP 2 - Attach the loading device or apply weights in such a manner that a load will be imposed parallel to the test bed and through the geometric center of the collector.

STEP 3 - Apply the load to 50% of the maximum filled collector weight at a rate faster than 25% of filled weight per second and hold for two (2) minutes.

STEP 4 - Remove load as quickly as possible.

STEP 5 - Repeat Steps 4 and 5 for a total of fifty (50) cycles.

STEP 6 - Inspect the collector and mountings for physical damage or distortion.

7.9.6 Data Requirements

Document applied loads and any physical structural damage, distortion or other degradation resulting from this test.

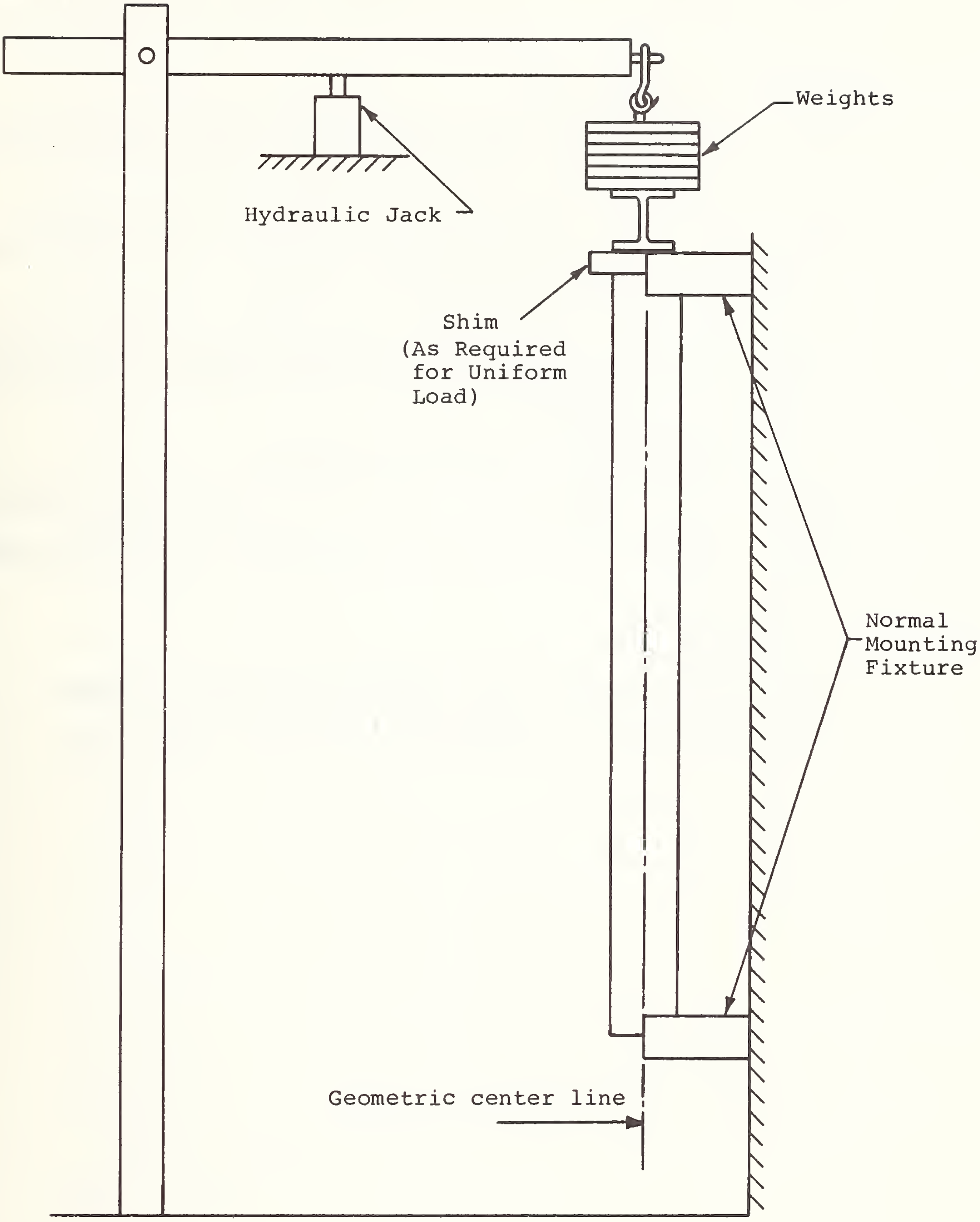


FIGURE 7. METHOD 2 - APPARATUS FOR VERTICAL LOAD TEST

STEP 5 - Repeat Steps 3 and 4 for a total of fifty (50) cycles.

STEP 6 - Inspect the collector and mountings for physical damage or distortion.

7.9.5.2 Method 2 (Vertical Test)

STEP 1 - Mount the collector parallel to a flat, rigid, vertical test frame such as the wall illustrated in Figure 7.

STEP 2 - Attach the loading device or apply weights in such a manner that a load will be imposed parallel to the test bed and through the geometric center of the collector.

STEP 3 - Apply the load to 50% of the maximum filled collector weight at a rate faster than 25% of filled weight per second and hold for two (2) minutes.

STEP 4 - Remove load as quickly as possible.

STEP 5 - Repeat Steps 4 and 5 for a total of fifty (50) cycles.

STEP 6 - Inspect the collector and mountings for physical damage or distortion.

7.9.6 Data Requirements

Document applied loads and any physical structural damage, distortion or other degradation resulting from this test.

7.10 Hail Loads

7.10.1 Purpose

The purpose of this test is to determine the ability of flat plate collector cover plate (glazing) to withstand impact forces from hailstones or similar flying objects.

7.10.2 Significance and Use

This test is intended to determine the ability of cover plates on flat plate collectors to withstand the impact forces of hailstones in various regions of the United States.

The maximum impact force to be imposed by this test shall be based on the manufacturer's stated regional limitation on the use of his collector. In the absence of such a regional limitation, the maximum impact force to be imposed shall be equivalent to that of a 1 1/2 in. hailstone falling at its resultant velocity (hailstone weighing 0.058 lb falling at 112 ft/sec). The maximum impact force to be imposed, when the manufacturer's regional limitation is stated, shall be based upon the maximum size of hail to be expected in the stated regions (See Reference [1], Section S-601-7 and Figure S-601-7; see also Appendix A-10) of the report.

This test is based on a procedure used by several laboratories in evaluating roofing and siding materials, but is not an established standard method. The test does not consider enviromental effects on materials properties, e.g. ultraviolet and thermal degradation. Therefore, this test should be considered developmental in nature.

7.10.3 Test Specimen

The test specimen shall consist of a complete collector panel and any mounting brackets or fixtures normally supplied with or specified by the manufacturer. The specimen shall be supported by and parallel to a rigid test frame by the mounting brackets or fixtures supplied with the collector or specified by the manufacturer.

7.10.4 Apparatus

The apparatus shall consist of the following:

A. A mechanism (hail gun) capable of propelling 1/2, 3/4, 1 and 1 1/2 inch diameter hailstones at their required velocities and also capable of being aimed so that the hail will strike the collector at the specified points (See Figure 8).

B. An instrument for measuring the hailstone velocities, to an accuracy of $\pm 2\%$, just prior to striking the collector.

C. Molds for forming round ice balls (hailstones) of 1/2, 3/4, 1 and 1 1/2 inch diameter.

D. A freezer controlled at $-10 \pm 10°F$ for storage of the ice balls.

E. A rigid test frame for support of the collector during the test.

7.10.5 Procedure

The test procedure consists of impacting the cover plate one time at each of the four specified points (Figure 8) with successively larger size hailstones or until some type of failure occurs. Failure is defined as fracture, cracking, tearing, puncture or permanent deformation sufficient to cause malfunction of the cover plate.

The impacts shall be as indicated in the following table within $\pm 2\%$.

Diameter of Hail (in)	Weight of Hail (lb)	Velocity at Impact (ft/sec)
1/2	0.002	83
3/4	0.007	91
1	0.017	98
1 1/2	0.058	112

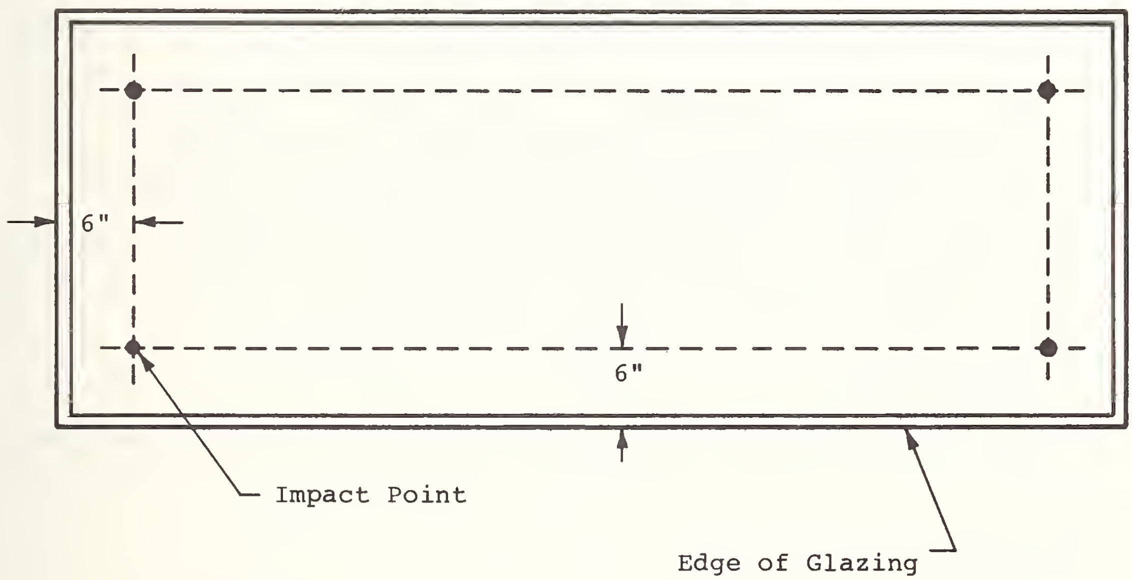
STEP 1 - Mount the collector to the test frame and position the hail gun so that the path of the ejected hailstones will be essentially perpendicular ($90° \pm 5°$) to the plane of the cover plate.

STEP 2 - Impact the cover plate at each of the four specified points (Figure 8) with one of the specified hailstones starting with the 1/2 inch diameter and consecutively increasing the size until all four points have been impacted, or until failure occurs.

STEP 3 - Measure the depth of any permanent deformation, describe other types of failure or deformation observed and note the impact at which they occur.

7.10.6 Data Requirements

Document any type of failure resulting from this test and the impact at which it occurred.



Impact points shall be within ± 1 inch of indicated point

FIGURE 8. IMPACT POINT LOCATIONS

7.11 Air Collector Rupture and Collapse

7.11.1 Purpose

The purpose of these tests is to determine the ability of air solar collectors to meet the pressure requirements established by Underwriters Laboratories [10] for the air duct systems into which they will be integrated.

7.11.2 Significance and Use

These tests are based on the requirements established for the rupture and collapse of air duct systems by Underwriters Laboratories [10]. These requirements for air duct systems have been incorporated into the building codes used by many jurisdictions. Since air collectors are generally incorporated directly into a building air duct system they can usually be considered as an extension of that air duct system. The positive pressure (rupture) test is intended to be run on those collectors which are recommended by the manufacturer for use with positive pressures. Similarly, the negative pressure (collapse) test is intended to be run on those collectors which are recommended by the manufacturer for operation with negative pressures. Negative pressure should be used if not specified.

7.11.3 Test Specimen

The test specimen shall consist of a complete solar collector panel assembly.

7.11.4 Apparatus

The apparatus shall consist of a pressure source, a means to regulate and control the pressure and a means to measure the pressure. The sources of positive pressure (for the rupture test) and of negative pressure (for the collapse test) shall be capable of providing positive and negative pressures of at least 2 1/2 times the manufacturer's rated positive and/or negative pressures, but not less than 1 1/4 inch water column. The inlet and outlet to the collector are to be sealed airtight by any means consistent with the use of the material under test. A pressure tap consisting of pipe or tubing is to be sealed into one end of the test sample and connected to a water manometer or equivalent pressure gauge which can be read directly to 0.05 inch water column. An air supply tap consisting of pipe or tubing is to be sealed into the same or other end of the sample and connected to a source capable of maintaining the specified positive or negative air pressure. The collector shall be maintained at ambient temperature throughout the test.

7.11.5 Procedure

STEP 1 - Check the pressure gauge or manometer for zero reading.

STEP 2 - Set the pressure regulator to ambient pressure.

STEP 3 - Attach the air supply to the inlet port of the collector.

STEP 4 - Apply a regulated pressure of 2 1/2 times the manufacturer's rated positive (rupture) or negative (collapse) pressure, but not less than 1 1/4 inch water column and maintain this test pressure for a period of one (1) hour.

STEP 5 - Inspect the collector and document any evidence of damage.

STEP 6 - Allow the specimen to return to ambient pressure.

STEP 7 - Check the pressure gauge or manometer for zero reading.

7.11.6 Data Requirements

Documentation of applied pressure, structural damage (e.g. breaks, tears, rips, openings, joint movement), evidence of excessive air leakage and dimensional changes, if any.

7.12 Static Pressure Leakage Test

7.12.1 Purpose

The purposes of these tests are to determine the leakage rate of air collectors, to detect leaks in liquid collectors and to indicate collector damage induced by other tests included in this report.

7.12.2 Significance and Use

The static pressure leakage test for air solar collectors parallels a requirement for air ducts established by Underwriters Laboratories [10]. The same basic test procedure can be used to determine the leakage in air collectors under both positive and negative pressure. Air collectors intended for operation under negative pressure shall be tested under negative pressure. Air collectors intended for operation under positive pressure shall be tested under positive pressure. Collectors shall be tested under negative pressure conditions when the manufacturer does not specify the conditions under which the collector should be used. The static pressure leakage tests for liquid solar collectors are based upon the hydrostatic and pneumatic tests established by the ASME Boiler and Pressure Vessel Code [11] for the routine testing of pressure vessels. The testing conditions are based on the maximum allowable working pressure which can be determined either by engineering analysis or by testing in accordance with the procedures established by the ASME code.

7.12.3 Test Specimen

The test specimen shall consist of a complete solar collector panel assembly.

7.12.4 Apparatus

The basic apparatus consists of pressure sources (either hydrostatic and pneumatic or pneumatic for liquid filled collectors; and pneumatic for air collectors), the necessary regulators to maintain the specified static pressure and appropriate gauges to indicate both pressure levels and leakage. Stable temperature conditions shall be maintained throughout the test to within $\pm 5°F$ of the initial ambient conditions.

7.12.4.1 Air Collector Apparatus

The inlet and outlet of the air collector are to be sealed airtight by any means consistent with the use of the material under test. A pressure tap consisting of pipe or tubing is to be sealed into one end of the test specimen and connected to a water manometer which can be read directly to 0.01 inch water column or to a pressure gauge of equivalent accuracy. An air tap consisting of pipe or tubing is to be sealed into the same or other end of the sample and connected to a source of positive air pressure (for collectors intended for operation with positive air pressure) or a means of creating and maintaining negative pressure (for collectors intended for operation with negative air pressure). An air volume meter accurate to within ± 0.50 cubic foot under the conditions of the test shall be placed in the air supply system between the supply source and the test sample. The meter is to indicate the total volume of air supplied to (positive pressure operation) or removed from (negative pressure operation) the sample over the period of the test.

7.12.4.2 Liquid Collector Apparatus

7.12.4.2.1 Overpressure Test

A pressure tap shall be installed in the collector outlet port which shall be sealed and capped. The collector inlet port shall be connected to either a hydrostatic source capable of providing and maintaining a hydrostatic test pressure of 1 1/2 times the manufacturer's specified maximum allowable working pressure or a pneumatic pressure source capable of providing and maintaining a pneumatic test pressure of 1 1/4 times the manufacturer's specified maximum allowable working pressure. When the hydrostatic apparatus is used, a small liquid safety relief valve set to 1 1/3 times the test pressure is recommended for the pressure test system, in case a vessel while under test is accidentally overpressurized (e.g. by overheating) with personnel absent. Indicating pressure gauges used in testing shall preferably have dials graduated over a range of about double the intended maximum test pressure but in no case shall the range be less than 1 1/2 times that pressure. The pressure gauges shall be accurate to within 0.5% of the full scale reading.

7.12.4.2.2 Leak Test

The apparatus shall consist of a pneumatic pressure source capable of applying a pressure equal to the manufacturer's maximum recommended working pressure, a valve capable of isolating the collector from the pressure source once it has been pressurized and a pressure gauge meeting the accuracy requirements specified in 7.12.4.2.1 which shall be used to detect pressure drops, if any.

7.12.5 Procedure

7.12.5.1 Air Collector Leak Test

STEP 1 - Check the pressure gauge or manometer for zero reading.
STEP 2 - Set the pressure regulator to ambient pressure.
STEP 3 - Attach the air supply to the inlet port of the collector.
STEP 4 - Apply 0.50 inch water column regulated positive pressure (for collectors operating under positive pressures) or 0.50 inch water column regulated negative pressure (for collectors operating under negative pressures) for one hour.
STEP 5 - Document the volume of air added (positive pressure) or removed (negative pressure) in order to maintain the required pressure during the period of the test.
STEP 6 - Allow the pressure to equalize to ambient.
STEP 7 - Check the pressure gauge or manometer for zero reading.

7.12.5.2 Liquid Collector Overpressure and Leak Test

STEP 1 - Check the pressure gauge for zero reading.
STEP 2 - Set the pressure regulator to ambient pressure.
STEP 3 - Attach the air supply of hydrostatic pressure source to the inlet port of the collector.
STEP 4 (Over Pressure Test) - Apply either a hydrostatic pressure equal to 1 1/2 times the manufacturer's specified maximum allowable working pressure (after pre-filling the collector with water) or a pneumatic air pressure equal to 1 1/4 times the manufacturer's specified maximum allowable working pressure. If the pneumatic pressure test is used, the pressure shall be gradually increased to not more than 1/2 of the required test pressure and then increased in steps of approximately 1/10 of the test pressure until the required test pressure has been reached.
STEP 5 - Allow the collector to equalize to ambient pressure. Then blow out all liquid from the collector if the hydrostatic test was used.

STEP 6 (Leak Test) - Apply a pneumatic (air) pressure equal to the manufacturer's specified maximum allowable working pressure; isolate the test specimen from the pressure source and record any changes in the reading of the pressure gauge that occur over a period of 15 minutes.

STEP 7 - Allow the pressure to equalize to ambient.

STEP 8 - Check the pressure gauge for zero reading.

7.12.6 Data Requirements

Documentation of the following:

Air Collectors - Applied pressure, calculated volume within the test specimen based on inside dimensions, total volume of air recorded by the air meter.

Liquid Collectors - Applied pressure and, if pressure drop is observed, the rate of pressure drop.

7.13 <u>Fire Test</u>

7.13.1 <u>Purpose</u>

The purpose of these tests is to determine the relative fire hazards created by roof-mounted, flat plate solar collectors exposed to an external fire source.

7.13.2 <u>Significance and Use</u>

This testing procedure is based on ASTM Standard E108 [12] which is used to determine the fire-retardant characteristics of roof coverings that are exposed to a fire originating outside the building on which they are installed. Provisions based on this ASTM procedure have been incorporated into the building codes used in many jurisdictions. Roof mounted solar collectors may have a significant effect on the fire retardant properties of such roof coverings. This testing procedure is intended for use in the DoE collector testing program (1) to determine the influence of roof mounted solar collectors on roof coverings, (2) to determine modifications in the basic testing procedure that may be required to make it applicable to solar collectors, and (3) to determine the effects on roofing of various generic types of collectors. As written, it is intended for use as a baseline testing procedure. Variations in test specimen configuration and in test conditions will be made during the course of the DoE collector testing program in order to determine the testing procedures that best characterize the hazard. At the present time, this testing procedure is primarily intended for use in exploratory testing.

7.13.3 <u>Test Specimen</u>

The test specimen shall consist of a complete collector panel assembly and any mounting brackets or fixtures normally supplied or specified by the manufacturer.

7.13.4 <u>Apparatus</u>

The test apparatus shall consist of that required in ASTM Standard E108 to perform the following tests:

A. Intermittent flame exposure
B. Spread of flame
C. Burning brand

Collector which, according to the manufacturer, may possibly be installed as an integral part of the roof assembly shall be mounted on the specified frame work with asbestos cement board to simulate eaves and cornices. Collectors which, according to the manufacturer, cannot be mounted as an integral part of the roof assembly shall be mounted on a roof deck section covered with a Class C covering material. Angles for the collector, roof deck and the stand-off distance shall be specified for the test. In either case the mounting procedure used shall be based on the manufacturer's recommended mounting practice. In any case where a single collector is not of adequate size to meet minimum test requirements, two or more panels may be connected as recommended by the manufacturer. All collectors shall be tested dry, i.e. without heat transfer fluid.

7.13.5 Procedure

One collector assembly shall be subjected to each of the following ASTM Standard E108 tests:

A. Intermittent flame exposure
B. Spread of flame
C. Burning brand

STEP 1 - Assure collector is dry (contains no heat transfer fluid).
STEP 2 - Prepare test set-up in accordance with Reference [12].
STEP 3 - Conduct required tests in accordance with Reference [12].

7.13.6 Data Requirements

7.13.6.1 Description of test specimen and mounting procedure.

7.13.6.2 Document data concerning both the collector assembly and roof covering materials for each of the tests in accordance with Reference [12].

8.0 REFERENCES

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[12] FIRE TESTS OF ROOF COVERINGS, ASTM Standard No. E-108-75, Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

APPENDIX A

PROPOSED RATING CRITERIA FOR FLAT PLATE SOLAR COLLECTORS

A-1 Thermal Performance (Paragraph 7.1)

The thermal performance of flat plate solar collectors shall be determined and reported in accordance with ASHRAE Standard 93-77 [4], and Appendix B of this document. Measurements made after the 30-day no-flow degradation test shall be used to determine performance.

A-2 30-Day No-Flow Degradation (Paragraph 7.2)

Collectors shall not exhibit a change in the product of $F_R(\tau\alpha)_e$ (intercept) or F_RU_L (slope) that would result in a 10% or greater decrease in thermal efficiency for the proposed application. Values of $\Delta T/I$ typical of the application under consideration (such as approximately 0.04 for domestic hot water, 0.08 for space heating and 0.11 for space cooling) should be used to determine the point on the efficiency curve that should be used to obtain the change in efficiency. In addition, the criteria in A-3 and A-4 shall be met during the 30-day no-flow test sequence.

A-3 Thermal Shock/Water Spray Test (Paragraph 7.3)

The collector shall not exhibit either of the following:

A. Visual observation of catastrophic or structural failure.*
B. Visual evidence of leakage for collectors designed to be waterproof.

A-4 Thermal Shock/Cold Fill Test (Paragraph 7.4)

The collector shall not exhibit either of the following:

A. Visual observation of catastrophic or structural failure.
B. Evidence of leakage rate greater than that allowed in Paragraph A-12.

A-5 Rain Test (Paragraph 7.5)

The collector shall not exhibit either of the following:

A. Visual observation of water penetration within the collector.
B. An increase in the weight of the collector by 1% or more.

---

*Failure that would not permit a collector to perform its intended function or that would result in the creation of a hazard.

A-6 Thermal Cycling Test (Paragraph 7.6)

The collector shall not exhibit either of the following:

A. Visual observation of catastrophic or structural failure.
B. Evidence of leakage rate greater than that allowed in Paragraph A-12.

A-7/A-8 Positive, Negative and Combined Loads (Paragraphs 7.7 and 7.8)

The procedures outlined below shall be followed to determine the design load ratings, U, assigned to a collector for positive live loads and for negative and combination wind loads. (The values of U required for a specific application can be determined in accordance with [8] by the system designer.)

The average maximum load (R_m) resisted by a collector sample during these tests should exceed the design load rating (U) by a factor which is a function of the number of specimens in the sample and of the variability in the materials used.

The design load rating (U) can be determined from the test results using the following relationship:

$$U = R_m(1-\alpha\nu)$$

where: R_m = the mean resistance, is the average maximum load resisted by the collector sample as determined by testing.

α = a factor dependent on the number of specimens (n) tested by a specific test method.

ν = coefficient of variation.

The factor α for 95 percent confidence limits may be taken from the following table:

n	α
1	3.29
2	2.81
3	2.59
4	2.47
5	2.38
10	2.17

The factor ν may be taken from the literature or from auxiliary tests. If variability data is not available a conservative estimate for ν should be used.

If only one test specimen is used per test method and if ν is equal to 0.2 (this coefficient is given in the literature for glass), then

$$U = 0.34\ R_m$$

The value of ν given above for glass shall be used in the absence of variability data for other materials that would affect the collector strength. However, the value of U obtained with this value of ν may be somewhat conservative for some materials. Similarly, if failures do not occur during the testing, the values of U calculated with the maximum test loads specified in this report will be conservative.

A-9 Longitudinal Load Test (Paragraph 7.9)

The collector or its mounting shall not exhibit visual evidence of physical damage or permanent distortion.

A-10 Hail Loads (Paragraph 7.10)

Collectors which are not damaged by the impact of 1 1/2 inch diameter hailstones will have a high probability of withstanding hailstorms in most regions of the United States without damage. The mean annual days with hail for various regions of the United States are indicated in Figure S-601-7 of Reference [1]. The impact from the 1 inch hailstones will apply to regions with up to 4 mean annual days with hail, the 3/4 inch hailstones to regions with up to 2 days and the 1/2 inch hailstones to regions with less than 1 day with hail per year.

A-11 Air Collector Rupture and Collapse (Paragraph 7.11)

The collector shall not exhibit visual evidence of catastropic or structural failure including rupture by breaks, tears, rips or other openings.

A-12 Static Pressure Leakage Test (Paragraph 7.12)

Air Collectors - The total volume of air recorded by the air meter from the time beginning with the establishment of the test pressure, to the end of the test period (one hour), is not to exceed 20 multiplied by the volume of the collector panel assembly [10].

Liquid Collectors - A pressure drop or visual evidence of leakage shall not occur.

A-13 Fire Tests (Paragraph 7.13)

A-13.1 General

The collector shall not reduce the fire resistance of a Class C [12] roof assembly. The collector shall be effective against light fire exposure. It shall not be readily flammable, shall afford a measurable degree of fire protection, and shall not slip from position or present a flying brand hazard. The intent is to indicate fire-resistance characteristics against fire originating from sources outside the building and should not be construed as having any significance with respect for suitability for use after fire exposure.

A-13.2 Rating Criteria

A-13.2.1 The collector must meet the requirements for a Class C rating given in Reference [12] for the intermittent flame, spread of flame and burning brand tests with the exception that only one series of tests shall be performed.

A. At no time during or after the intermittent flame, spread of flame, or burning brand tests (1) shall any portion of the collector be blown or fall off the test deck in the form of flaming or glowing brands that continue to glow after reaching the floor or (2) shall the roof deck be exposed or portions of the roof deck fall away in the form of particles that continue to glow after reaching the floor.

B. At no time during the intermittent-flame tests shall there be sustained flaming of the underside of the deck.

C. In the burning brand tests there may be sustained flaming on the underside of the deck of not more than 20% of the brands applied.

D. At the conclusion of the spread of flame tests, the flaming shall not have spread beyond 13 ft (the top of the deck). There shall have been no significant lateral spread of flame from the path directly exposed to the test flame.

A-13.2.2 The flame spread classification index, as measured by ASTM Standard E-84 [5] for all insulation materials shall not exceed the following values:

Plastic Foam	75
Other Insulation Material	150

A-13.2.3 Materials used as duct liners shall comply with the requirements of Paragraph 5.3 of Reference [10] for Class 1 air ducts.

APPENDIX B

CALCULATION OF ALL-DAY SOLAR COLLECTOR EFFICIENCY

The series of solar collector tests conducted according to ASHRAE Standard 93-77 results in a determination of the thermal efficiency of the collector at "near-normal-incidence" conditions as a function of the difference between the inlet fluid temperature to the collector and the ambient temperature as well as the incident solar radiation normal to the collector plane. In addition, the parameter "incident angle modifier" is determined which allows one to predict how the thermal efficiency changes as the angle between the direct solar beam and the outward drawn normal to the collector plane increases. From these two performance factors, it is possible to predict the "all-day" collector efficiency. In order to complete the calculation for a given day, it is necessary to know the following as a function of time throughout the day:

1. inlet fluid temperature to the collector, $t_{f,i}$,
2. ambient temperature, t_a
3. incident solar radiation in the plane of the collector, I_T ,
4. collector $F_R\,(\tau\alpha)_{e,n}$ and incident angle modifier.

The calculation procedure is carried out in a series of steps indicated in the following table.

Measurements made after the 30-day no-flow degradation test shall be used to determine performance.

TABLE B-1. TYPICAL COMPUTATION OF ALL DAY SOLAR COLLECTOR EFFICIENCY

CALCULATION STEPS	HOUR OF THE DAY, SOLAR TIME												DAILY TOTAL
	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	
1. Inlet fluid temp to collector, $t_{f,i}$, °C	49	49	49	49	50	50	51	52	54	54	54	54	
2. Ambient air temp, t_a, °C	10	10	10	13	15	16	16	22	24	24	18	18	
3. Incident radiation on collector plane, I_T, W/m^2, (Table A2, ASHRAE 93-77)	90	186	454	693	876	993	1031	993	876	693	454	186	7525
4. Collector thermal efficiency at normal incidence, determined in accordance with Sections 8.3.2 and 8.5 of ASHRAE 93-77 and using data from lines 1, 2, and 3.	--	.02	.15	.38	.42	.46	.46	.46	.43	.42	.18	.02	
5. Incident angle between the direct solar beam and outward drawn normal to the collector plane, θ	90	75	60	45	30	15	15	30	45	60	75	90	
6. Incident angle modifier, determined in accordance with Sections 8.3.3 and 8.6 of ASHRAE 93-77 and using the value of θ from line 5.	--	.48	.82	.93	.97	1.0	1.0	.97	.93	.82	.48	--	
7. Energy output from the collector, W/m^2, (line 3)x(line 4+ $[F_R\{\tau\alpha\}_{e,n}]$x [{line 6}-1])	--	0	0	229	350	457	474	437	333	180	0	--	2460
8. Collector thermal efficiency, line 7/ line 3													.33

APPENDIX C

THE DOE COLLECTOR TESTING PROGRAM*

TO: Interested Solar Collector Manufacturers

Interim Collector Thermal Performance Testing Program

The Department of Energy invites solar collector manufacturers to participate in a Federally-sponsored collector testing program. This program is part of a joint Government/industry effort to accelerate the development and implementation of a certification, rating and labeling program for solar collectors. The Solar Energy Research and Education Foundation (SEREF), under contract to DoE, is developing procedures for certifying, rating and labeling solar collectors.

The DoE is sponsoring the testing of solar collectors. The test data will be used by SEREF to produce a catalog of collector ratings. It is expected that this program will stimulate the implementation of an ongoing industry certification program.

This program will also insure the identification of reliable, durable solar equipment for the consumer and is responsive to the tax credit provisions of the proposed National Energy Act.

Tests will include the thermal performance of solar collectors in accord with ASHRAE Standard 93-77, a 30 day stagnation test, fire resistance, structural and environmental tests in accord with NBSIR 77-1305. The ASHRAE test is a consensus standard, data from which can form the basis for a rating, labeling, and certification program. All collectors in the program will be tested per the ASHRAE test and the 30 day stagnation test. The other tests documented in NBSIR 77-1305 are considered to be tentative and in need of confirmation or modification, therefore data will be gathered from collectors considered representative of a sufficiently large class. These data will help develop the appropriate test procedures and requirements for future consensus standards. Thermal and stagnation tests will be duplicated in some cases to determine whether climatic variation affects the test results.

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*The above material was included in a notice sent by DoE to solar collector manufacturers.

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15. SUPPLEMENTARY NOTES

This report is the first revision to NBSIR 77-1305, "Provisional Flat Plate Solar Collector Testing Procedures."

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This document represents the first revision to NBSIR 77-1305. The test methods contained in this report and the provisional rating criteria presented in an appendix are intended for use in determining the thermal performance, and to aid in the assessment of the safety and durability/reliability of flat plate solar collectors. These test methods and rating criteria have been selected after the review of over 400 accepted industry standards and are consistent with the intent of the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards (MPS) and the Interim Performance Criteria (IPC) prepared by the National Bureau of Standards (NBS) for the Department of Energy (DoE) and HUD respectively. Many of the test methods and rating criteria contained in this report are preliminary in nature and will be evaluated during a collector testing program being sponsored by DoE. It is, therefore, recommended that regulatory agencies consider the developmental status of these procedures in evaluating their suitability for adoption. It is intended that revisions will be made as more experience is gained and inputs received from appropriate industry representatives, testing laboratories, designers, etc.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Durability/reliability; fire safety; rating criteria; solar collectors; structural performance; testing procedures; thermal performance

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